Using Cognitive Work Analysis to design smart grid interfaces

Christine Chauvin, Philippe Rauffet, Mathilde Tréhin, Pascal Berruet, Julie Lassalle

Using Cognitive Work Analysis to design smart grid interfaces

Christine Chauvin, Philippe Rauffet, Mathilde Tréhin, Pascal Berruet, & Julie Lassalle
Lab-STICC UMR CNRS 6285, University of South Brittany
France

Summary

Smart grids are electricity networks that can intelligently integrate the behaviour and actions of all users connected to them in order to deliver sustainable, economic, and secure electricity supplies efficiently. They provide a tool for consumers to control their consumption better and, in the end, to save energy. The issue is that electricity-consuming activities are habitual and routinized ones, and modifying these habits is extremely difficult. This paper indicates how the Cognitive Work Analysis framework could be used to design an interface facilitating users' comprehension of energy consumption and subsequent adoption of new behaviours.

Introduction

The promotion of sustainable consumption is an important aspect of sustainable development. However, sustainable electricity consumption appears to be a particularly difficult challenge, and households seem to constitute a particularly difficult target group (Fischer, 2008). Smart grids could be an opportunity to address energy challenges. The concept relates to "an electricity network that can intelligently integrate the behaviour and actions of all users connected to it, in order to efficiently deliver sustainable, economic and secure electricity supplies" (SmartGrids European Technology Platform, 2013). Smart grids may provide tools for consumers to control their consumption better and, in the end, to save energy. A smart grid system may transform passive consumers into decision-makers who will play a positive role in environmental issues. They might thus become "prosumers" (Mah et al., 2012) or "consum'actors", that is to say, responsible consumers. In France, Electricité Réseau Distribution France (Electricity Distribution Network France) is modernizing the electrical grid and substituting smart meters for standard meters. Pilot projects, like the smart grid SOLENN project carried out in the area of Lorient (South Brittany), aim to develop and test information and support tools for consumers equipped with smart meters. These tools should help households become more aware of their electricity consumption.

In D. de Waard, K.A. Brookhuis, A. Toffetti, A. Stuiver, C. Weikert, D. Coelho, D. Manzey, A.B. Ünal, S. Röttger, and N. Merat (Eds.) (2016). Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2015 Annual Conference. ISSN 2333-4959 (online). Available from http://hfes-europe.org

Several studies (Mah et al., 2012; Toft et al., 2014; Perlaviciute & Steg, 2014) have identified obstacles as well as enabling factors that influence the acceptability and acceptance of smart grids. Obstacles are related to the users' fears. Some people fear invasion of their privacy due to data breaches, a degradation of the quality of service due to the possibility of power modulation, and the complexity of the system. The main drivers are related to financial incentives on the one hand and to social or environmental motivations on the other. Several authors (Kobus et al., 2013; Goulden et al., 2014) have emphasized the role that may be played by information systems in the process of acceptance of smart grids. This role is negative when they deliver data that are not easy to understand and when they seem to be "opaque". In contrast, they may facilitate behaviour changes when they are intuitive, flexible, and when they provide frequent feedback. Kobus et al. (2013) stressed that electricity is used within the context of routinized actions (turning the light on, for example), which rely on automatic processes. The major issue is therefore to design interfaces that could spark and support the development of new consumption habits.

In this paper, the Cognitive Work Analysis (CWA) methodology is used to define the main principles of an interface that could facilitate habit-changing processes. The CWA methodology was proposed by Rasmussen (1986), Rasmussen et al. (1994), and further developed and codified by Vicente (1999). This framework is used to design "ecological interfaces" designed to help knowledge workers adapt to change and novelty (Vicente, 2002). It has already been used in a large number of systems. To our knowledge, however, it has never been employed to model a smart grid system. It is a formative constraint-based approach, consisting of five successive stages: Work Domain Analysis, Control Task Analysis, Strategies Analysis, Social Organization and Cooperation Analysis, and Worker Competencies Analysis. Three of these stages are presented in this paper: Work Domain Analysis (WDA), Control Task Analysis (ConTA) and Worker Competencies Analysis (WCA). The work presented here is carried out within the context of the SOLENN project.

Method

As recommended by Stanton and Bessell (2014), interviews were used as primary source of information for construction of the products in CWA. Since the system doesn't exist yet, a semi structured interview format was used that is similar to the format described by Bisantz et al. (2003). In such an interview, questions put to experts are motivated by the concepts of the Work Domain Analysis. Experts questioned were the project manager and three information tools designers of the SOLENN project. Information collected during collective meetings, as well as documents analysis, served also to consolidate the analyst's understanding. After phase one (WDA) was completed, the functions identified were used in the subsequent phases (ConTA and WCA), to offer different perspectives on the system.

Work Domain Analysis

The WDA is the most important stage of the CWA methodology. WDA deals with the constraints that are placed on actors by the functional structure of the field or the environment in which the work occurs. This phase is associated with a modelling tool, the Abstraction Hierarchy, which can be used to break down any work domain in terms of:

- *ends* (purposes, goals) and *means* (to reach the goals) according to an implementation hierarchy;
- *whole* and *parts* according to a decomposition hierarchy.

The implementation hierarchy enables the description of a work domain in terms of five levels of abstraction: functional purpose (the purpose of the work domain, its “raison d’être”), priority measures/ abstract functions, general functions, physical processes and activities, and physical resources and their configurations. Each level is connected by a structural means-end framework linked to the next upper or lower level. It is a causal structure in physically coupled systems, obeying the laws of nature. Hence, the future system states may be predicted. The hierarchy is an intentional structure in human-activity systems such as the smart grid one. In these cases, “causality is observed through the interaction of social rules between groups of participants, and future states of the system cannot be similarly predicted” (Wong et al., 1998, p. 147).

The decomposition hierarchy is destined to break a domain down into sub-systems, then each sub-system into functional units, each unit into sub-sets, and finally each sub-set into components. Both hierarchies are used to define the informational content and structure of an interface (Vicente & Rasmussen, 1992).

Control Task Analysis

ConTA is related to the activity required for meeting the purpose of a system. Naikar et al. (2006) proposed to characterize this activity as a set of recurring work situations, work functions, or control tasks. Work functions are related to functions to be performed in a work system. They are defined at the purpose-related function level or at the object-related process level in the abstraction hierarchy (Jenkins et al., 2008). They may be performed in different work situations.

Worker Competencies Analysis

Worker competencies are related to the modes of cognitive control that may be required to realize a control task. WCA relies on the Skill-Rule-Knowledge taxonomy proposed by Rasmussen (1986) to distinguish three kinds of cognitive control modes:

- the skill-based level involving the use of automated behaviours with no conscious control (such as mental math calculations) and patterns of automated and highly integrated actions;
- the rule-based level involving the correspondence of an “if-then” type between signs and an appropriate action (if such a sign is present, then such an action is executed);

- the knowledge-based level involving declarative knowledge. This level corresponds to sequential and analytical reasoning that is based on an explicit representation of goals and a mental model of the functional properties of the environment. Using it is costly because it requires focused symbolic attention.

Results

Work Domain Analysis and Abstraction Hierarchy

Table 1 shows the Abstraction Hierarchy of a smart grid system. The system was refined into three levels: the whole system (smart grid at territory level), sub-systems (each household fitted with a smart meter), and the function units in which electricity is used.

The main purpose of a smart grid system (i.e. functional purpose) is to deliver sustainable, economic, and secure electricity supplies (Toft et al., 2014). The SOLENN project has two main purposes: *i)* securing the electricity supplies in order to decrease the risk of load shedding, and *ii)* optimizing the energy consumption; the latter concerns the system at both territory and household level.

Values and priority measures represent the criteria that must be respected for a system to meet its functional purposes. Criteria are fundamental laws, principles, or values that can serve as a basis for the evaluation. In a smart grid system, the main criteria concern the measurement of the energy demand: *i*) at territory level, energy demand should be less than the maximum electricity production capacity; *ii*) at the household level, energy demand should be less than the available kVA power, consumption should be as limited as possible, given the main features of the household (number of persons), the dwelling (surface, year of construction), and the environment (location, season, outside temperature). Consumption must decrease towards an optimum bounded by an acceptable level of comfort. Several reference values (in kWh per year) could be considered: a theoretical optimum, the mean consumption of similar profiles, past consumption of a specific household in a similar context. Consumption decreasing can also be translated into expense decreasing (in euros) and carbon footprint decreasing (CO2). It is important to represent these functional relations explicitly on the interface, so that operators can determine when the process constraints are broken (Vicente & Rasmussen, 1992).

The third level (Purpose-related functions) represents the functions that a system must be capable of supporting, so that it can fulfil its functional purposes. A smart grid system can modulate the available power remotely (in case of network congestion or incident), deliver information to the energy producer, the supplier, and the consumer, and provide information for the management of energy consumption. At the household level, the main function consists in managing the electricity consumption. This function can be considered at the level of function units: managing the electricity consumption related to heating, producing warm water, etc.

The fourth level (Object-related processes) represents the functional processes or the functional capabilities or limitations of the physical objects in a system. Among the objects listed at the fifth level, it is important to notice that the number of the current clamps is limited (to three or four). It is therefore not possible to know the consumption of each device. Furthermore, information is not transmitted continuously but according to discrete time steps. The power of each electric device is also a feature that must be taken into account.

Table 1. Abstraction Hierarchy of the smart grid system in the SOLENN project.

	Smart grid at territory level	Household level	Function units
Functional purposes	Securing the electricity supply, managing the electricity demand	Optimizing electricity consumption (i.e., obtaining reasonable consumption with a good level of comfort)	
Values & priority measures	Avoiding load shedding; energy demand< maximum energy production; minimizing consumption (GWh); reducing peak load, straightening load curb	Energy demand < kVA power; reducing electricity consumption (kWh), electricity expenses (€) and carbon footprint ($CO2$)	
Purpose-related functions	Modulation of the available power; consumer information and coaching.	Managing the electricity consumption	Heating, producing warm water, cooking, lighting, cooling, washing dishes, washing clothes, drying, cleaning, using electronic devices
Object-related processes		Level of information breakdown, time step of information delivery	Power of each device, power demand and duration of use
Physical objects	Linky information system	Smart meters (Linky) Electric switch Sub-metering system Website, applications	Electric devices Computers, tablets

The last level may represent physical or artificial objects (such as artefacts and infrastructure). In the SOLENN project, the main physical and artificial objects that may be installed in the household or made available to the consumers are:

- a smart meter (enabling a two-way communication between the meter and the central system and supplying information concerning the daily consumption);

- current clamps and a sub-metering device (enabling the measure of the individual circuit of energy demand and providing information regarding the consumption of specific devices or groups of devices);
- electric devices;
- websites and individual applications (providing information regarding consumption at defined time steps, showing the load profile);
- individual and collective coaching (offering consumers advice).

The Abstraction Hierarchy (AH) provides an informational basis, since the model may be converted into a list of variables. Its main benefit is to provide information that would be useful to cope with unanticipated events. As explained by Bisantz and Vicente (1994, p. 84), AH is intended to represent the set of goal-relevant constraints governing the operation of the controlled system. This type of representation can be described as event-independent, since it provides information about system structure that is independent of any specific event or consequence of events. This is in contrast to representations that are event-dependent, consisting of the symptoms or corrective procedures associated with a set of events, or classes of events, which must be identified beforehand. This last type of work domain representation cannot, by definition, help operators consistently cope with unanticipated events.

In the case of smart grid systems, specific recommendations have already been given concerning the information that should be delivered to the consumer (Lewis et al., 2012; Bouchet & Chauvin, 2015). The Abstraction Hierarchy model adds new recommendations concerning the display of the process constraints and the display of possibilities for actions within these constraints. They are, at the household level, *i*) the display of the electricity demand compared to the kVA available power, and *ii*) the display of electricity consumption results compared to a reference value.

Control Task Analysis

As said before, activity required for meeting the purpose of a system may be characterized as a set of work situations, work functions, or control tasks.

In the case of a smart grid system, two main situations may be distinguished: normal and incidental situations. The incidental situations are related to constraints affecting the electric grid such as peak loads. In such cases, three work functions are expected: power modulation, consumer information, and consumer response /action by reducing consumption levels.

The decision ladder is used to decompose activity into a set of control tasks for each work situation and/or work functions. It uses the formalism defined by Rasmussen to model a diagnosis and decision task (Rasmussen, 1986). In this formalism, rectangular boxes represent information-processing activities and circles represent states of knowledge resulting from these activities.

Figure 1 shows the different stages of the task realised in order to manage the electricity consumption in incidental situations. A similar figure could be drawn for normal situations.

The ascending left side of the ladder brings together all the steps of situation analysis (from detecting abnormal conditions to evaluating consequences on the system status). The descending right side of the ladder relates to the various steps of action planning (task specification, then procedure) and ends with the performance of the action itself.

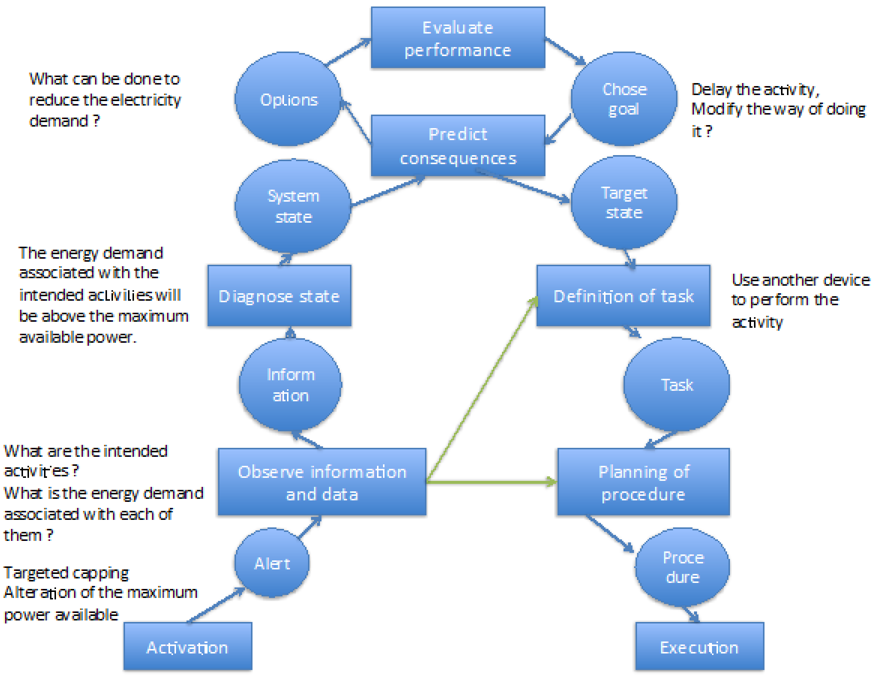

Figure 1. Model of the "management of electricity consumption" control task in incidental situations.

In incidental situations, the control task begins when consumers are informed about a targeted capping or about a change in the maximum power they can draw. The stages following the activation consist in: *i)* estimating future consumption by considering intended uses or activities, *ii)* comparing the desired consumption with the new limit and determining whether it is under or above it, *iii)* predicting consequences (are the foreseen activities possible or not?), *iv)* examining what could be done to reduce the electricity demand, *v)* choosing a goal, which could be either to delay the activity or to modify the manner of doing it, and *vi)* in the latter case, deciding to use another device to perform the activity.

The decision ladder also shows alternative routes (i.e., shortcuts) connecting the two sides, thus signalling expert operators' heuristic decision making. Heuristic decision making corresponds to operators' know-how and rests upon inductive reasoning that associates states of the environment to actions that have been shown as successful in similar situations. It thus depends on empirical correlations between evidence and actions observed in familiar scenarios.

From a practical point of view, such a model brings useful elements to the identification and display of important information (the new maximum power, the energy demand associated with a given activity, etc.); in that sense, it complements the Work Domain Analysis. It also leads to considering the possible ways to support expert behaviours such as helping users understand the relation between particular activities, devices, and energy demand (see Figure 2). In that sense, task analysis complements the Worker Competencies Analysis.

Worker Competencies Analysis

The Skill-Rule-Knowledge taxonomy is highly relevant for the design of smart grid interfaces. One of the main issues is to break up routinized behaviours that are not reflected upon and that may be seen as "environmentally detrimental habits" (Matthies, 2005; Fischer, 2008) and to induce a conscious decision so that new norms and considerations should be taken into account. This approach induces, first, extra effort but the creation of new routines is expected at a medium term.

Fischer (2008) indicated that several kinds of feedback may be used to support such a decision process, assuming that "feedback is most effective if it: *i*) successfully captures the consumer's attention, *ii*) draws a close link between specific actions and their effects, *iii*) activates various motives that may appeal to different consumer groups, such as cost savings, resource conservation, emissions reduction, competition, and others" (p. 83). Concerning the second point, Fischer explained that successful feedback involves appliance-specific breakdown. Costanza et al. (2012) showed that consumers go beyond the disaggregation of appliance loads, and deal with higher levels of abstraction such as "oven roast dinner". Such reflections about consumption patterns facilitate the creation of rules (i.e., rule-based level) associating specific consumption events (described in terms of start and end timestamps and the amount of energy consumed) and specific activities involving the use of one or more electrical appliances.

Towards an ecological interface

The twofold objective of an ecological interface is to encourage the use of skill-and rule-based behaviour while providing support for otherwise more effortful behaviour to cope with unfamiliar and unanticipated situations (Vicente, 2002). In the case of a smart grid system, one of the main goals is to provide support for effortful behaviour, so that the user can elaborate rules - or action schemes - facilitating understanding and decision-making in normal or incidental situations. To this end, several information elements must be presented together. The Abstraction Hierarchy and the Control Task Analysis facilitate their identification. These information elements are the criteria to be respected and their value, all the active work functions at the function unit level (for example, washing clothes, heating, producing warm water, washing dishes), the devices used (washing machine, heaters, boilers, dishwasher) and their characteristic features (typical duration of use and consumption).

As pointed out earlier, the number of the current clamps is limited, and it is therefore not possible to measure the consumption of each device directly. However, users could manually note their energy consumption log on a load curve, as proposed by Costanza et al. (2012). The system could then analyse the consumption associated with a specific event and display this information. Figure 2 shows a summary representation of the information collected. It compares devices used for the same activity with numerical and graphic representations and highlights the amount of energy used for each activity. This representation would help users determine the most energy-intensive devices for a given period. It intentionally uses the two notions of power (W) and energy (Wh) to facilitate the learning of those concepts.

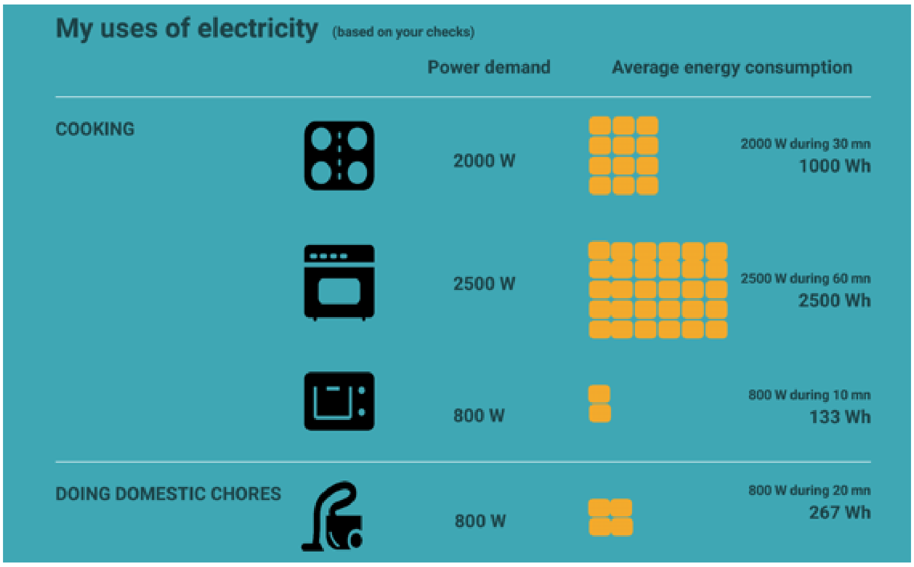

Figure 2. Displaying the average energy consumption per device and activity. Icons were created in the context of the Noun Project (https://thenounproject.com/).

This information would help consumers evaluate their possibilities of use in an incidental situation. Figure 3 shows that they could manipulate boxes representing specific uses, in order to check what is possible, given the reduction of available power. This function would help users plan their domestic tasks in a constrained situation, owing to the simultaneous representation of *i)* the energy demand associated with each activity and *ii)* the maximum available energy. It is not simply a static representation, as in the proposal by Costanza et al. (2012), since users could play an active role. By manipulating blocks representing specific uses, consumers could check the configurations of devices that would be allowed, given that the available power will be reduced. In this way, users could anticipate, develop skills, and adopt new reflex actions in restrictive situations. Once again, what is expected thanks to repeated use of such an interface is the creation of new consumption habits.

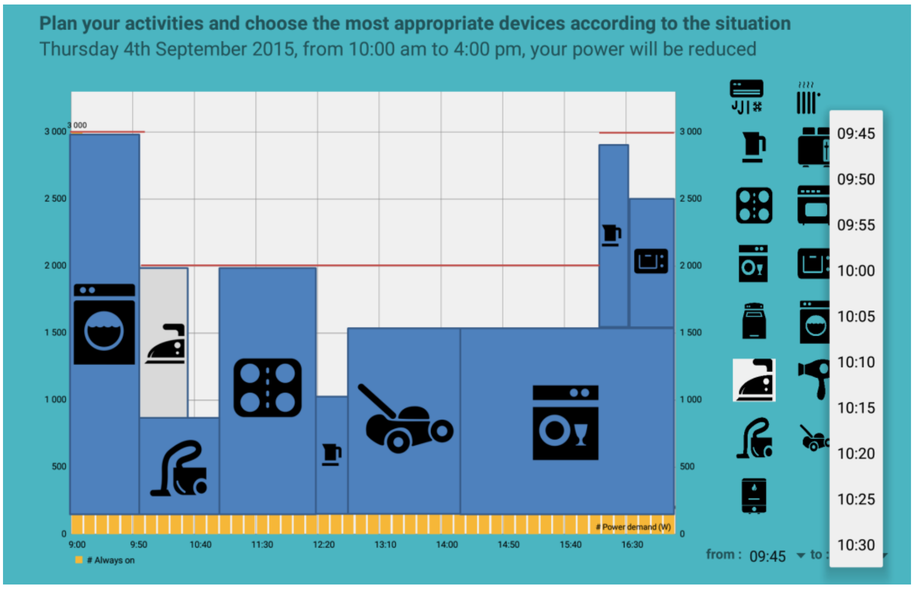

Figure 3. Displaying the range of possibilities given the available power

Conclusion

Bennett and Flach (2011) summarized the goal of an ecological interface when viewed through the lens of Work Domain Analysis on the one hand and of the decision ladder on the other. At the WDA level, it is to make the constraints at all levels of the abstraction hierarchy visible; ideally, "the operator should be able to see the state of the work domain in relation to the goals, the costs, and the fields of possibilities associated with physical and regulatory laws and organizational layout" (Bennett & Flach, 2011, p.103). When considering the decision ladder, they recommended that the representation provide signals and signs that map directly onto states/ constraints of the work processes to support productive thinking (e.g., chunking, automatic processing, and recognition-primed decisions). It seems possible and relevant to apply these principles to the design of a smart grid interface. Showing the consumption associated with specific use as well as the maximum available power should help consumers understand their consumption and adopt new uses. This proposal will be tested with the trial participants taking part in the SOLENN project.

Cognitive Work Analysis is useful for designing a new, first-of-a-kind system. It is based, in this case, on Engineering-Expert-Knowledge. In the framework of the SOLENN project, this analysis will be completed by interviews with users equipped with a Linky smart meter and by observations focusing on their use of the information and support tools. At this stage of the study, we will investigate the utility and usability of the interface, its capacity to improve the users' understanding and management of their consumption, as well as the system's acceptance.

Besides Cognitive Work Analysis, other approaches could be used to design information tools for smart-grid systems. An alternative could be to induce the desired behaviour thanks to pervasive technologies (Fogg, 2009) or with positive reinforcements and indirect suggestions as advocated by the "nudge" approach (Thaler & Sunstein 2008).

Acknowledgments

This work was carried out within the context of the SOLENN project supported by the Environment and Energy Mastery Agency (Agence de l'Environnement et de la Maîtrise de l'Energie - ADEME) as part of the French government-led Investments for the Future Programme.

References

Bennett, K.B., & Flach, J.M. (2011). *Display and interface design: Subtle science, exact art*. Boca Raton: CRC Press.

Bisantz, A.M., & Vicente, K.J. (1994). Making the abstraction hierarchy concrete. *International Journal of Human-Computer Studies*, *40*, 83-117.

Bisantz, A.M., Roth, E., Brickman, B., Gosbee, L.L., Hettinger, L., & McKinney, J. (2003). Integrating cognitive analyses in a large-scale system design process. *International Journal of Human-Computer Studies*, *58*, 177-206.

Bouchet, M., & Chauvin, C. (2015). IHM persuasive et pilotage des actions de Maîtrise de l'Energie. In N. Bonnardel, L. Pellegrin, and H. Chaudet (Eds.), *Actes du Huitième Colloque de Psychologie Ergonomique (EPIQUE 2015)*. Paris, France: Arpege Science Publishing.

Costanza, E., Ramchurn, S.D., & Jennings, N.R. (2012). Understanding domestic energy consumption through interactive visualisation: a field study. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing* (pp. 216-225). ACM.

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency*, *1*, 79-104.

Fogg, B.J. (2003). Persuasive Technology. *Using computers to change what we think and do.* Amsterdam: Morgan Kaufmann.

Goulden, M., Bedwell, B., Rennick-Egglestone, S., Rodden, T., & Spence, A. (2014). Smart grids, smart users? The role of the user in demand side management. *Energy Research & Social Science*, *2*, 21-29.

Jenkins, D.P., Stanton, N.A., Salmon, P.M., Walker, G.H., & Young, M.S. (2008). Using cognitive work analysis to explore activity allocation within military domains. *Ergonomics*, *51*, 798-815.

Kobus, C.B., Mugge, R., & Schoormans, J.P. (2013). Washing when the sun is shining! How users interact with a household energy management system. *Ergonomics*, *56*, 451-462.

Lewis, P.E., Dromacque, C., Brennan, S., Stromback, J., & Kennedy, D. (2012). *Empower demand 2: Energy efficiency through information and communication technology – best practice examples and guidance*. Technical Report. VaasaETT, Global Energy Think Tank. [Online] Available from: www.esmig.eu/sites/default/files/final_empower_2_demand_report_final_distr 2.pdf.

Mah, D.N.Y., van der Vleuten, J.M., Hills, P., & Tao, J. (2012). Consumer perceptions of smart grid development: results of a Hong Kong survey and policy implications. *Energy Policy, 49*, 204-216.

Matthies, E. (2005). Wie können Psychologlnnen ihr Wissen besser an die PraktikerIn bringen? Vorschlag eines neuen, integrativen Einflussschemas umweltgerechten Alltag shandelns. [How can psychologists improve their outreach towards practitioners? A suggestion for a new, interactive model of environmentally sound everyday practices]. *Umweltpsychologie, 9,* 62 – 81.

Naikar, N., Moylan, A., & Pearce, B. (2006). Analysing activity in complex systems with cognitive work analysis: concepts, guidelines and case study for control task analysis. *Theoretical Issues in Ergonomics Science*, 7, 371-394.

Perlaviciute, G., & Steg, L. (2014). Contextual and psychological factors shaping evaluations and acceptability of energy alternatives: integrated review and research agenda. *Renewable and Sustainable Energy Reviews, 35*, 361-381.

Rasmussen, J. (1986). *Information processing and human–machine interaction*. Amsterdam: North Holland.

Rasmussen, J., Pejtersen, A.M., & Goodstein, L.P. (1994). *Cognitive systems engineering*. New York: Wiley.

Smart Grids - European technology platform. (2013). European technology platform for the electricity networks of the future - FAQs about ETP Smart Grids.

Stanton, N. A., & Bessell, K. (2014). How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis. *Applied Ergonomics, 45*, 110-125.

Thaler, R.H, Sunstein, C.R. (2008). Nudge: Improving decisions about health, wealth, and happiness. *Constitutional Political Economy*, *19*, 356-360.

Toft, M.B., Schuitema, G., & Thøgersen, J. (2014). Responsible technology acceptance: model development and application to consumer acceptance of Smart Grid technology. *Applied Energy, 134*, 392-400.

Vicente, K.J. (1999). *Cognitive work analysis: toward safe, productive, and healthy computer-based work*. Mahwah, NJ: Erlbaum.

Vicente, K.J. (2002). Ecological interface design: progress and challenges. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *44,* 62-78.

Vicente, K.J., & Rasmussen, J. (1992). Ecological interface design: theoretical foundations. *IEEE Transactions on Systems, Man and Cybernetics, 22*, 589-606.

Wong, W.B., Sallis, P.J., & Hare, D.O. (1998). The ecological approach to interface design: applying the abstraction hierarchy to intentional domains. In P.B Calderon and B. Thomas (Eds.), *Computer Human Interaction Conference, 1998. Proceedings. 1998 Australasian* (pp. 144-151). Los Alamitos, CA: IEEE Computer Society Press.